(NASA-CR-97648) VISUAL OBSERVATION OF PLANETARY PROBES ON MANNED ENCOUNTER MISSIONS TO MARS (Bellcomm, Inc.) 10 p

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SUBJECT: Visual Observation of Planetary Probes on Manned Encounter Missions to Mars
Case 710

DATE: September 19, 1968

FROM: C. L. Greer

ABSTRACT

The feasibility of using a 40" telescope to visually observe a flashing beacon on a probe at the time of midcourse maneuver from a manned spacecraft approaching Mars has been studied. If the probe is seen against a star field background, visual observation appears feasible for probe arrival times less than 24 hours before manned spacecraft periapsis. For a probe viewed against a fully illuminated planet, probes arriving less than 4 hours before manned spacecraft periapsis may be visually observed. It is also shown that a lander probe on a fully illuminated planet which is subresolution 1 hour before manned spacecraft periapsis can be observed at this time by using a strobe light requiring less than 34 joules per flash.

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MEMORANDUM FOR FILE

Introduction

It has been suggested that, on manned encounter missions to Mars, a 40" astronomical telescope be used as an angle measuring device to aid in determining the trajectory of probes launched from the manned spacecraft to the planet.[1,2] At least two types of applications have been identified. One is the tracking of a probe in flight before and after a midcourse maneuver. A second case would be the location of a lander probe on the planet surface. This would apply to the Mars Surface Sample Return (MSSR) probe[3] where its position on the Mars surface must be determined to specify launch conditions.

The object of this paper is to determine conditions under which a strobe beacon on the probe can be observed using a 40' telescope at the manned spacecraft.

The analysis considers manned spacecraft V_∞'s in the range from 4 km/sec to 10 km/sec, which includes most of the Mars encounter missions, and probe arrival times from 2 hours to 24 hours before manned spacecraft periapsis.

Probe Arrival Times

Of the possible Mars encounter missions, only the 1975 single planet mission has been studied in any detail. An experiment payload has been postulated[3] and a mission sequence plan outlined.[4] The probe payload consists of three aero-drag probes, a photographic orbiter, a geophysical lander, and an MSSR vehicle. The corresponding mission sequence plan schedules the aero-drag probes to arrive at 24, 20, and 16 hours before manned spacecraft periapsis. The photographic orbiter arrives 3.5 hours before spacecraft periapsis, and the MSSR and geophysical lander arrive at 2.4 and 2 hours early, respectively.

A general experiment payload for dual planet missions to Mars and Venus is described in Reference 5. The only probes considered for a Mars encounter were MSSR probes. A general mission sequence plan does not exist but it is expected that the MSSR probes would be scheduled to land 2 to 4 hours before spacecraft periapsis.

For the midcourse maneuver strategy used the separation distance at the time of midcourse is maximum for the 24 hours early arrival and minimum for 2 hours early arrival. These values of time of arrival were taken as extrema, so the analysis is valid for intermediate times of arrival.

Probe Midcourse Maneuver

The optimal midcourse maneuver or maneuvers for probes have not been determined. The procedure used in Reference 2 was to perform a single midcourse maneuver when a probe had completed one half of its flight. The strategy used in this study is to inject the probes at $4*10^6$ km with a single midcourse maneuver at 4 hours before probe entry. This procedure was shown to be optimum, under certain error assumptions, for probes arriving 12 to 24 hours before spacecraft periapsis.[6] The range at probe injection is consistent with other studies for small ΔV injection requirements,[7] and delaying the midcourse until 4 hours before probe entry produces larger separation distances than performing the maneuver after one half of a probe's flight. Since the illumination from a point source is inversely proportional to the square of the separation distance, this analysis is valid for midcourse maneuvers at smaller separation distances.

Useful Approximations

The following set of approximations is easy to use and is accurate to two places.

Time from spacecraft periapsis at a distance D

(1) $$T = D/V_\infty .$$

ΔV requirements for a probe to reach the planet at time ΔT before spacecraft periapsis

(2) $$\Delta V = \frac{\Delta T}{T-\Delta T} * V_\infty .$$

Separation distance at time ΔC before probe entry

(3) $$R = \Delta V(T-\Delta T-\Delta C).$$

Substituting for ΔV in Equation (3) from Equation (2)

$$(4) \qquad R = \Delta T * V_\infty * (1-\frac{\Delta C}{T-\Delta T}).$$

The accuracy of the approximations was determined by using a two body targeting program with V_∞'s of 8.56 km/sec and 4.0 km/sec, probe early arrival times of 24 and 2 hours, probe injection when the spacecraft was $4*10^6$ km from the planet, and separation distance between probe and spacecraft computed at 4 hours before probe impact with the planet. The numerical study indicates that approximations are accurate to two places for $V_\infty \geq 4$ km/sec, $D \geq 1*10^5$km, $\Delta C \geq 4$ hours, and $\Delta T \geq 2$ hours.

Visual Tracking of Probes

In a previous study D. B. James[2] investigated the feasibility of visually tracking probes for a 1975 Mars encounter mission. It was assumed that the probe would be seen against a fully illuminated planet and that a probe would be visible if it appeared as large as a resolution element. Whether a probe is seen against a star field background or a planet background is a function of the probe target point, time of arrival, and time of visual tracking. The present study considers probe visibility against a star field background and a planet background.

If a probe is seen against a star field background, it must appear as bright as a 6th magnitude star to the eye of the observer. This brightness is the standard limit of visibility. The illuminance, L, (illumination incident upon a surface) from a 6th magnitude star is $1.05*10^{-2}$ lumens/km^2. Assuming 1/10 of a second is the response time, T, of the eye, the integrated illuminance, LT, received by the eye is $1.05*10^{-3}$ lumens-sec/km^2. At the separation distances under consideration, a probe with a light source will appear as a point source of light. The equation for illuminance at a distance R from a point source with luminous flux F in lumens is

$$(5) \qquad L = \frac{F}{4\pi R^2}.$$

If the luminous flux is focused into a beam of light with cone angle α, the equation for illuminance at a distance R becomes

$$(6) \qquad L = \frac{F}{2\pi R^2(1-\cos(\alpha/2))}.$$

The light gathering power of a 40" telescope may be estimated by assuming the diameter of the lens of the human eye to be 1/5". The gain of a 40" telescope under this assumption is

$$G = \left(\frac{40}{\frac{1}{5}}\right)^2 = 4.0*10^4.$$

The equation for illuminance using a telescope with gain G and focusing into cone angle α with 50% efficiency is

$$(7) \qquad L = \frac{FG}{4\pi R^2(1-\cos(\alpha/2))} .$$

For a cone angle of 5°, integrated illuminance of $1.05*10^{-3}$ lumen-sec/km^2, and a gain of $4*10^4$, the integrated luminous flux required is

$$TF = 3.13*10^{-10} * R^2 \text{ lumen-sec.}$$

The range at midcourse maneuver for a probe arriving 24 hours early with a V_∞ of 10 km/sec is $8.24*10^5$ km. The integrated luminous flux requirement is 213 lumen-sec. Using a strobe light generating 50 lumen-sec/joule would require 4.3 joules. At a pulse repetition rate of 1 per second, the average power required is 4.3 ~~watts. Thus, considering only average power requirements, visual~~ tracking of probes with a star field background is feasible for distances less than $8.24*10^5$ km.

If an illuminated planet is the background for a probe, the problem becomes more complicated. The brightness of the Mars surface will be $.15*13.4/R^2$ lamberts where .15 is the geometric albedo, 13.4 is the solar visual constant, and R is the distance from the sun in A.U.'s. Perihelion of Mars is 1.38 A.U., hence the maximum brightness of Mars is 1.06 lamberts. In Reference 8, the illuminance required for visibility of a steady source against backgrounds of various brightnesses was determined. The authors state that the illuminance requirements may well be a factor of two too large because of the manner in which the experiments were conducted. Also a flashing light may require less illuminance for detection than a steady source but this factor was not considered. For a background of 1.06 lamberts, the illuminance required for steady source visibility is 35 lumens/km^2.

Thus, the illuminance requirements for a fully illuminated planet background are $3.33 * 10^3$ greater than the requirements for a star field background.

Assuming a capability of $3.14*10^4$ lumen-sec which is the output from a Xenon flashtube*, visual tracking of probes with a 40" telescope is possible at separation distances less than $1.73*10^5$ km. The separation distance at time of midcourse for a V_∞ of 10 km/sec and 4 hours early arrival is $1.38*10^5$ km which implies that probes arriving 4 hours early with V_∞'s less than 10 km/sec may be visually tracked against an illuminated planet background.

Locating MSSR Probes

The location of an MSSR probe must be determined in order to specify the launch conditions to achieve rendezvous with the spacecraft. The MSSR lands 11° beyond the planetary limb, which requires 44 minutes of planet rotation before line of sight contact with the spacecraft is made. The MSSR probes arrive 2 to 4 hours early[5], thus line of sight is available for 1 to 3 hours before spacecraft periapsis. At 1 hour before spacecraft periapsis the range to the planet is $1.7*10^4$ km for a V_∞ of 4 km/sec and $3.9*10^4$ km for a V_∞ of 10.0 km/sec. At these ranges an MSSR is subresolution with a 40" telescope. The results of the preceding section show that a strobe light would be visible at these ranges even on a fully illuminated planet. The energy requirement of such a source at a range of $4 * 10^4$ km is 1674 lumen-sec. The energy requirement per flash is 34 joules for a strobe light generating 50 lumen-sec/joule. Thus the MSSR could be observed 1 hour before spacecraft periapsis.

Conclusion

Visual tracking of probes with a 40" telescope against a star field background is feasible. Assuming a Xenon strobe light with an output of 31,400 lumen-sec requiring 600 joules input, and a reflector with a beam width of 5°, and 50% efficiency, visual tracking of probes against a fully illuminated planet is possible for early arrival times less than 4 hours. The MSSR probes can be observed on a fully illuminated planet 1 hour before manned spacecraft periapsis by using a strobe light requiring less than 34 joules per flash.

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*EG & G Inc. FX-29 requires 600 joules input and generates $3.14*10^4$ lumen-sec.

Acknowledgment

The author's thanks to Miss P. A. Whitlock for the numerical results from the two body targeting program.

1014-CLG-gml C. L. Greer

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